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Primary stability and stiffness in ankle arthrodesis-crossed screws versus anterior plating

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Abstract: **BACKGROUND:** Ankle arthrodesis is commonly used for the treatment of osteoarthritis or failed arthroplasty. Screw fixation is the predominant technique to perform ankle arthrodesis. Due to a considerable frequency of failures research suggests the use of an anatomically shaped anterior double plate system as a reliable method for isolated tibiotalar arthrodesis. The purpose of the present biomechanical study was to compare two groups of ankle fusion constructs - three screw fixation and an anterior double plate system - in terms of primary stability and stiffness. **METHODS:** Six matched-pairs human cadaveric lower legs (Thiel fixated) were used in this study. One specimen from each pair was randomly assigned to be stabilized with the anterior double plate system and the other with the three-screw technique. The different arthrodesis methods were tested by dorsiflexing the foot until failure of the system, defined as rotation of the talus relative to the tibia in the sagittal plane. Experiments were performed on a universal materials testing machine. The force required to make arthrodesis fail was documented. For calculation of the stiffness, a linear regression was fitted to the force-displacement curve in the linear portion of the curve and its slope taken as the stiffness. **RESULTS:** For the anatomically shaped double-plate system a mean load of 967N was needed (range from 570N to 1400N) to make arthrodesis fail. The three-screw fixation method resisted a mean load of 190N (range from 100N to 280N) ($p=0.005$). In terms of stiffness a mean of 56N/mm (range from 35N/mm to 79N/mm) was achieved for the anatomically shaped double-plate system whereas a mean of 10N/mm (range from 6N/mm to 18N/mm) was achieved for the three-screw fixation method ($p=0.004$). **CONCLUSIONS:** Our biomechanical data demonstrates that the anterior double-plate system is significantly superior to the three-screw fixation technique for ankle arthrodesis in terms of primary stability and stiffness.

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**PRIMARY STABILITY AND STIFFNESS OF ANKLE ARTHRODESIS
TECHNIQUES – CROSS SCREWS VERSUS ANTERIOR PLATING**

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ABSTRACT

BACKGROUND

Ankle arthrodesis is commonly used for the treatment of osteoarthritis or failed arthroplasty. Screw fixation is the predominant technique to perform ankle arthrodesis. Due to a considerable frequency of failures research suggests the use of an anatomically shaped anterior double plate system as a reliable method for isolated tibiotalar arthrodesis. The purpose of the present biomechanical study was to compare two groups of ankle fusion constructs - three screw fixation and an anterior double plate system – in terms of primary stability and stiffness.

METHODS

Six matched-pairs human cadaveric lower legs (Thiel fixated) were used in this study. One specimen from each pair was randomly assigned to be stabilized with the anterior double plate system and the other with the three-screw technique. The different arthrodesis methods were tested by dorsiflexing the foot until failure of the system, defined as rotation of the talus relative to the tibia in the sagittal plane. Experiments were performed on a universal materials testing machine. The force required to make arthrodesis fail was documented. For calculation of the stiffness, a linear regression was fitted to the force–displacement curve in the linear portion of the curve and its slope taken as the stiffness.

RESULTS

For the anatomically shaped double-plate system a mean load of 967N was needed (range from 570N to 1400N) to make arthrodesis fail. The three-screw fixation method resisted a mean load of 190 N (range from 100N to 280N) ($p=0,005$). In terms of stiffness a mean of 56N/mm (range from 35 to 79 N/mm) was achieved for the anatomically shaped double-plate system whereas a mean of 10 N/mm (range from 6 to 18 N/mm) was achieved for the three-screw fixation method ($p=0,004$).

CONCLUSIONS

Our biomechanical data demonstrates that the anterior double-plate system is significantly superior to the three-screw fixation technique for ankle arthrodesis in terms of primary stability and stiffness.

Keywords: Ankle Arthrodesis – Fixation techniques – Biomechanical comparison

69	PRIMARY STABILITY AND STIFFNESS OF ANKLE ARTHRODESIS
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INTRODUCTION

Ankle arthrodesis provides a reliable means in order to treat symptomatic end-stage ankle arthritis and is a valuable procedure to reconstruct the hindfoot after failed total ankle arthroplasty (1-7). There is a multitude of surgical solutions available to perform tibiotalar arthrodesis including internal and external fixation devices (8-16). Crossed-screw techniques are most frequently used as internal fixation implants (17). The literature reports inconsistent failure rates from 0% up to 58% (18-20). The treatment of symptomatic nonunion after ankle fusion can be challenging and complex. Therefore it would be preferable to avoid any revision surgery. It has been suggested that the use of plates (alone or in combination with cross screw fixation) would reduce the frequency of nonunion and failures with promising clinical results (21-25). More recently an anatomically shaped anterior double plate system was found to be a very reliable tool to achieve an isolated tibiotalar fusion. In a consecutive series of 29 patients presenting difficult bone conditions, solid fusion was achieved in all ankles. One year after surgery, 25 patients (86%) were satisfied, and all but one patient would have undergone the same surgery again (26).

The purpose of the following biomechanical study was to compare two groups of ankle fusion constructs – three-screw fixation and an anterior double plate system - in terms of primary stability and stiffness. Our hypothesis was that the anterior double plate system provides superior fixation to the three screws technique.

MATERIALS AND METHODS

Six matched-pairs of human cadaveric lower legs (using Thiel histologic fixation) were used in this study (27). The average age of bodies was 76 years (range 41-92). For all ankle specimens dual energy x-ray absorptiometry (DEXA) scans were performed to evaluate the relative projectional bone mineral density (BMD). The mean projectional BMD was 0.64 g/cm² (range 0.42 to 0.81 g/cm²). All cadaver specimens were obtained from the Anatomical Institute of the University. Before death all individuals agreed by written consent, that their

bodies could be used for scientific purposes. Every written consent has been filed in order to track the specimen.

All specimens were cut 10 centimeters distally to the knee joint line.

The pair matching was performed according to the projectional BMD. One specimen from each pair was randomly assigned to be stabilized with the anterior double plate system (Tibiasys, Integra, Plainsboro, NJ/Newdeal, Lyon, France) and the other with the three-screw technique. Osteotomy of the lower leg was performed 10cm distal to the knee joint.

Surgical Techniques

Both techniques have been performed using a classic anterior approach to the ankle joint. The incision averaged 10-12 centimeters starting in the midline of the anterior lower leg and extending downwards over the talonavicular joint line. The cartilage of the tibial plafond and the talar body was completely removed until exposing the subchondral bone plate. All ligaments were left intact. With the foot hold in neutral position a 2.0mm Kirschner wire was inserted from the distal tibia into the talus. The position was checked by fluoroscopy.

Anatomically shaped double-plate system (Tibiasys, Integra, Plainsboro, NJ/Newdeal, Lyon, France)

First the lateral plate was applied to the talus and fixed by means of three screws, which were driven into the talar head and neck. Angular stability was obtained by adding a fixation cup. Compression at the tibiotalar fusion site was achieved using a special compression device, which was fixed to the second proximal screw hole of the lateral fusion plate and to the tibial shaft by means of a monocortical screw. In order to standardize the manually exerted compression force at 200N a single component press force sensor was mounted on the compression device of the implant (Kistler Group, sensor type 9313AA1, Winterthur, Switzerland) (Fig. 1A). Interlocking screws were used to fix the plate to the tibia, while the talus was pushed against the medial malleolus. Subsequently, the shorter anteromedial plate

was applied to the talus and tibia and fixed with interlocking screws. To reach the posterior aspect of the talus one oblique screw was inserted through each of the two plates.

Crossed-screw fixation

The crossed-screw fixation has been performed according to the technique described by Zwipp et al (20). For fixation 6.5mm cancellous screws were used. Two screws were inserted parallel from the anterior aspect of the distal tibia into the posterior part of the talar body. A third screw was inserted through a posteromedial stab incision 3 cm proximal to the tip of the medial malleolus. The screw was inserted into the anterolateral portion of the talar head. To compare isolated tibiotalar arthrodesis only, we disclaimed inserting the forth screw (as originally described), fixating the distal fibula to the talus.

Radiographic control showed correct screw and plate positioning for all simulated ankle fusions (Figs. 2-3).

Biomechanical testing

The lower leg specimens were mounted on a custom clamping frame that fixed the proximal tibia. It consisted of a steel ring and shell that engaged with the proximal tibia. In addition crossing screws that were driven across the ring and shell provided further support to the loading system (Fig. 1B).

The different fusion techniques were tested by flexing the ankle dorsally until failure of the system, defined as rotation of the talus relative to the tibia in the sagittal plane.

Experiments were performed on an universal materials testing machine (model 1456; Zwick, Ulm, Germany). To eliminate forefoot motions during biomechanical testing the foot was placed in a carbon soled shoe (Fig. 1C). The entire plantar aspect of the foot was put on an horizontal metal table. The foot was positioned in a way that the malleolus was vertically aligned with the axis of a hinge joint under the plate allowing the ankle to flex dorsally. In the starting position, the foot was positioned at a 90 degree angle in relation to the tibia. This set up was mounted on two linear bearing sleds (SFERAX SA, Cortaillod, Switzerland)

positioned perpendicularly in the horizontal plane, to remove the effect of mediolateral and anteriorposterior forces on the foot.

A compressive preload of 100N was applied on the proximal end of the tibia to ensure contact between the foot and flexing plate throughout the entire test. While maintaining this force, the distal end of the tibia was fixed to the testing machine with the custom clamping system with radially oriented screws. Afterwards, the machine load was removed. Subsequently, the fusion system was tested flexing the foot dorsally until failure. To do so the actuator of the testing machine was attached to an adjustable metal string pulling the plate at the height of the metatarsal heads to induce dorsal foot flexion around the hinge axis. From the starting position, a constant displacement of 100mm/min was imposed and the load-displacement curve was recorded until failure of fixation. Two Kirschner wires were inserted into the distal tibia and the talus to allow for direct visual control of relative motion between at the ankle joint (Fig. 1D). Both Kirschner wires were glued together. The slightest crack within the glue indicated failure of the system. The time of failure was noted and compared with the digital results obtained by the testing machine. Load to failure (N) and stiffness of the constructs (N/mm) was assessed.

Statistics

A paired two sided t-test was used to compare the results obtained with the double plate system and the three-screw fixation technique. Level of significance was set at $p=0.05$.

RESULTS

The double-plate system had significantly greater load-to-failure and stiffness than the 3-screw method (Table 1). For calculation of the stiffness, a linear regression was fitted to the force–displacement curve in the linear portion of the curve (R^2 average value was 0.984, with a range from 0.948 to 0.996) and its slope taken as the stiffness.

DISCUSSION

The present study demonstrates a superior biomechanical behavior of the anterior double-plate system when compared with the classic crossed-screw fixation technique in terms of primary stability and stiffness and supports the clinical findings reported by Plaass et al (26). We think that it is important to discuss the significance of biomechanical performances among different fusion techniques. While crossed-screw fixation is a widely accepted method for tibiotalar fusion it shows variable union rates in the literature (19). In addition, screw placement is difficult to standardize and varies from patient to patient. Large diameter screws cross the fusion site, leaving only minimal bone structure to heal. Repetitive drilling of new screw holes to re-position the implants weakens the bone. This might become even more problematic in patients with osteopenic /-porotic bone who are at greater risk (18,19). Besides proper handling during surgery, any fixation should also be strong enough to facilitate postoperative rehabilitation. Many decades ago, Charnley stated that besides meticulous preparation of the fusion site, rigidity and compression of a fixation device are important factors to achieve adequate union (28,29). While the biology of ankle fusion is very difficult to test and assess the authors focused on biomechanical factors. The goal was to analyze the strength of two different fixation systems that base on the same concept: The tension-band effect (anterior compression by the implant and posterior compression through the pull of the Achilles tendon). The difference between the systems is that the anterior double-plating system preserves large osseous contact surfaces enhancing the probability of adequate and stable bone healing. Because of the results obtained by the current study the authors have

adopted their postoperative rehabilitation protocol regarding earlier weightbearing in the postoperative period.

Although many different biomechanical studies for ankle arthrodesis techniques have been performed, we are not aware of any study comparing an anterior double-plate system with the classic three-screw fixation technique (17,30-35).

There are several limitations for our study. First our sample size with only twelve Thiel-fixated lower legs is small. This might be negated by the small p-values achieved for dorsiflexion forces and stiffness. Second the experimental setup does not represent physiologic gait. However dorsiflexion is the major stress for a fused ankle during normal gait (36). We therefore chose load to failure in dorsiflexion. In addition, the ligaments were preserved. As such during passive dorsiflexion (exerted by the testing machine) the joints followed their axes of motion. Third, the biomechanical properties of Thiel-fixated specimen are not the same compared to living bone or fresh-frozen specimen. As we were not able to acquire fresh-frozen specimens for the biomechanical testing we chose the Thiel-fixation to allow for adequate range of motion properties (37). Alternatives to Thiel-fixated specimen would have been formalin-fixated specimens or artificial bone. However formalin-fixated specimens become approximately five times stiffer and lose the nonlinear load-deformation characteristics with increased range of motion while the Thiel fixation maintains non-linear load-deformation (37). Zech et al showed different biomechanical characteristics of artificial bone compared to cadaver bones (embalmed and fresh-frozen) for mechanical testing without relevant differences between embalmed and fresh-frozen specimens. Their results do not support the use of artificial bone for biomechanical implant testing (38). We did not perform any cost analysis. Anterior double-plate system is more expensive than a simple crossed-screw technique. However, in the light of revision surgery, such a device could have its place providing enough stability in the presence of weak bone quality.

CONCLUSIONS

The present biomechanical data demonstrates that the anterior double plate system has a greater primary stability when compared with a classic crossed-screw technique. Whether

222 this will improve postoperative rehabilitation after ankle fusion or not is still subject for future
223 clinical and radiographic research.

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LEGENDS TO THE FIGURES

Fig. 1. Biomechanical setting

(A) Compression device with press force sensor and digital compression force registration device. (B) Custom clamping frame allowing proximal tibia fixation. (C) The foot was placed on a carbon soled shoe to eliminate forefoot motions. (D) Kirschner wires fixed in the tibia and talus for visual control of motion between the ankle joint.

Fig. 2. Radiographs after double plate fixation.

Fig. 3. Radiographs after three-screw fixation.